FACT SHEET 03-08 8-28-03

Dam Safety: Seepage through Earthen Dams

Most dams have some seepage through or around the embankment as a result of water moving through the soil structure. The rate at which water moves through the embankment depends on the type of soil in the embankment, how well it is compacted, the foundation and abutment preparation, and the number and size of cracks and voids within the embankment. Many seepage problems and failures of earth dams have occurred because of inadequate seepage control measures or poor/incomplete cleanup and preparation of the foundations and abutments. Seepage can lead to soil piping and embankment sloughing or sliding, both of which can lead to dam failure. Therefore, seepage must be controlled to maintain dam integrity and safety.

Detection

Seepage can emerge anywhere on the downstream face, embankment toe, or abutments at or below the normal pool level. Seepage will appear as soft wet areas, areas with flowing water, areas where the vegetation is noticeably lush and green, areas where the embankment is sloughing or bulging, or areas containing ponded water. Cattails, reeds, mosses, and other marsh vegetation are often present in seep areas. Rust-colored iron bacteria are another indication of water seeping from the ground. Figure 1 shows extensive seepage at the toe of an embankment.

Figure 1 - Seepage at embankment toe caused sloughing

In this case, the vegetation on the face of the embankment is dormant while that at the toe is growing vigorously. The seepage has caused minor sloughing with a resultant scarp formation (at the arrow). If the seepage forces are large enough, soil can be eroded from the embankment or foundation resulting in piping or boils. Figure 2 shows a boil near the toe of an embankment. In this case, it appears seepage is flowing under the embankment in the foundation soils. Piping is often associated with “muddy flows” as sediment is

Figure 2 - Boil near toe of embankment (12-inches diameter)

carried out of the embankment (or foundation) with the water. Also, piping may occur along the discharge conduit.

Sinkholes may develop on the surface as internal erosion removes soil from below ground. Serious seepage may create whirlpools in the lake upstream of the embankment. Whirlpools are usually a precursor to dam failure.

Boils occur downstream of the embankment toe and are usually an indication of seepage under the embankment. Boils are formed when the seepage pressures are high enough to erode the surface soils. A conical mound of soil often forms around the boil if the soils are granular.

Seepage can also develop behind or beneath concrete spillways or headwalls. The signs of this type of problem may be cracking, heaving, or rotating of the structure. Freezing and thawing will amplify the effects of seepage at concrete structures.

A continuous or sudden drop in the normal pool level is another indication of seepage. In this case, the seepage is usually significant enough to result in flowing water downstream of the dam. This condition will require frequent and close monitoring.

Saturation of embankment soils, abutments, and foundations due to seepage generally result in reduced soil strengths leading to sloughing, sliding, and instability. In the worst case, seepage can result in total embankment failure if left unchecked.

Normal seepage through a relatively impervious dam embankment may be un-noticeable. The emerging seepage may evaporate or be taken up by the vegetation as fast as it occurs. This type of seepage generally poses no problems.

Thorough inspections are required to detect seepage. Seepage may be difficult to spot due to vegetation. Probing the soil in suspect areas can help to locate and identify whether seepage is present and the limits of the problem. Differences in vegetation and flowing water on the downstream side of embankments are the two most noticeable signs of seepage. Soft soil areas and soil sloughing may also be signs of seepage from the reservoir.

Figure 3 – Seepage flows on vegetated embankment

Other factors may produce signs that appear to be seepage. Poor surface drainage may result in wet areas at the downstream toe or along the abutments of the embankment. Natural springs at or under the embankment, or in the groin of the abutments often have the same appearance as seeps. Monitoring of these conditions will still be required to ensure that the dam is not degraded.

Common Causes of Seepage

Seepage that results in piping, boils, or soil erosion is generally caused by the following conditions:

- poor compaction of embankment soils
- unsuitable embankment soils
- poor foundation and abutment preparation
- rodent holes, rotted tree roots and wood
- open seams, cracks, or joints in rocks in dam
- foundations or abutments
- coarse gravel or sand in the foundation or abutment
- cracks in rigid drains, reservoir linings, or dam cores
- cracks or breaks in conduits, or poor conduit joints
- lack of filter protection on the downstream face
- clogging of coarse drains
- filters or drains with pores so large soil can wash through
- frost action
- shrinkage cracking in the embankment soil
- settlement of embankment soil
- uprooted trees
- earthquakes

Seepage that results in saturation and excessive seepage forces is generally caused by the following conditions:

- insufficient structural drainage
- unsuitable embankment soils
- poor embankment compaction
- poor foundation and abutment preparation
- trapped groundwater on the abutment or foundation
- excessive uplift pressures
- water collecting behind structures because of insufficient drainage
- water flowing into cracks on the embankment surface
- poor grading or improper drainage of crest
- localized settlement on crest

Monitoring

Regularly scheduled monitoring and inspection is essential to detect seepage and prevent dam failure. The state of Indiana requires professional inspections every two years for high hazard dams. However, more frequent inspections should be performed by the owner or his representative. The inspection frequency should be based on the hazard classification of the dam; high hazard dams require inspection more frequently than low or significant hazard dams. At a minimum, all dams should be visually inspected at least every six months, before a predicted major storm event, during or after severe rainstorms or snowmelts, and after an earthquake. All new dams should be inspected weekly after construction is complete and reservoir filling is ongoing, and for at least two months after the reservoir has been filled.

Dam inspections performed on a regular basis are the most economical aid a dam owner can use to assure the safety and long life of the structure while reducing liability risks.

If seepage is detected on a dam embankment or foundation, it should be closely monitored on a regular basis until it is corrected. Seepage flows should be measured if possible and photographed to track its progression. If piping or boils are present, the size and the depth of the exit opening should be measured and recorded at each inspection, and the turbidity of the water should be noted. If the seepage is causing sloughing, sliding, or settlement, the affected area should be measured and recorded. The length, width, and depth of these conditions should be measured and photographed at each inspection. Sketches of the location of the seepage or instabilities should be prepared for the dam records.

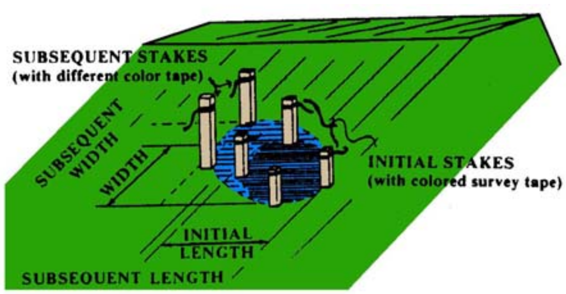

Figure 4 – Staking wet area to record changes

Surveys of the seepage, sloughing, slides, or other deficiencies may be required on large dams.

Piezometers can be installed into the embankment to monitor water levels in the soil fill. Typically, seepage will increase if the water level in the embankment rises. High water levels may also be used to predict seepage problems before they develop.

Control

If seepage flows increase or embankment soils are showing signs of instability, corrective action should be implemented quickly. Seepage problems at high hazard dams need to be corrected immediately; if allowed to progress, they may result in loss of life and property downstream of the dam. A qualified geotechnical engineer or dam safety professional should be contacted for inspection and advice for all high hazard dam seepage problems.

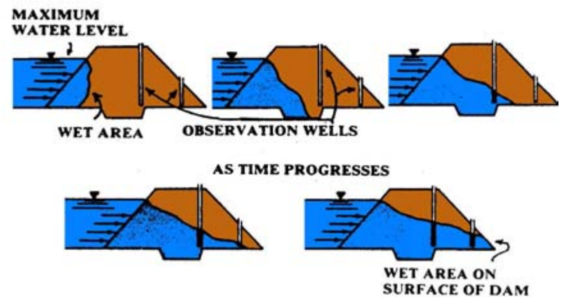

Figure 5 – Progression of seepage through dam embankment

The type of controls deployed will depend on the source, type, and extent of seepage. If excessive water is flowing from soil piping or boils, or if the water is carrying sediment, a qualified geotechnical engineer or dam safety professional should be contacted to perform an inspection and to develop recommendations for further actions. The reservoir level should be lowered if serious piping or embankment sliding/sloughing is occurring, and the cause of the condition corrected. Reservoir drains, pumps, or siphons may be used to drawdown the water level.

Sloughing and sliding due to seepage at the toe of the embankment may be corrected by removing the unstable soil and constructing a toe drain with filter. This same remedy can be applied to areas where water is flowing but piping has not yet occurred. Unstable soils located at higher levels on the embankment should be removed and replaced with re-compacted, cohesive soil. The water level in the reservoir should be lowered if significant repairs are required on the embankment.

Seepage, piping, and boils in existing dams may be corrected, or slowed, by intercepting the water before it exits on the downstream side of the dam.

Typical methods include: impermeable upstream blankets, cutoff trenches in the embankment, grout curtains, sheet pile walls, relief wells, and toe drains. Impermeable upstream blankets, or liners, are the most effective method, but require complete drawdown of the reservoir. These blankets may consist of low-permeability soil or a synthetic geo-membrane. The blankets may also be deployed on

the floor of the reservoir to prevent foundation seepage.
Temporary corrective actions for boils or seeps below the embankment toe include installing a weighted filter in and over the boil exit opening. Loose soil should first be removed from the hole. A layer of filter sand should be installed in the bottom of the hole, covered by a medium-sized coarse aggregate. A larger aggregate should then be placed at the top of the hole; the final layer must

Figure 6 - Apparent seepage along this concrete spillway caused total erosion of the structure.

consist of aggregate that is heavy enough to resist the uplift force of the seeping water. A qualified engineer should be contacted for inspection and advice for significant seepage problems.

New dams should be designed and constructed to control seepage before problems develop. The dam foundation should be carefully prepared by removing all organic matter and unsuitable soils. If gravel or sand is present in the foundation, a cutoff trench should be constructed through the coarse strata if possible. The embankment soils should be a cohesive soil placed in thin lifts (6 to 9 inches thick after compaction) and compacted to 90% Modified Proctor density. Spillway conduits should be properly installed and backfilled to prevent seepage along the conduits. Internal or toe drains should be constructed if seepage is expected to exit on the embankment downstream face. Filters must be used to prevent soils from blocking the drains. Dams can be constructed wide enough to keep the phreatic surface from exiting on the embankment downstream slope.

Trees and brush should be removed from embankments. Regular mowing of embankments should be performed to prevent trees from growing. Trees that are less than 12 inches in diameter may be cut flush with the ground and the roots left in place. Trees greater than 12 inches in diameter should be removed completely. After the tree is cut down, the root ball and major roots should be extracted; the root ball cavity must then be cleaned and backfilled with compacted soil. If seepage is present in the cavity, a filtered drain should be installed to prevent soil piping. A complete toe drain may be required if a sufficient number of trees are removed. A filtered drainage system or weighted filter may be installed in the cavity from trees that are removed downstream of the embankment toe. All Disturbed and repaired areas must be regarded and planted with a suitable grass mix.

Cracks and erosion rills on the embankment should be filled, re-graded, and re-seeded. Burrowing rodents should be eliminated from dams, and any damage they created should be repaired by backfilling with soil or a filtered drain.

Consequences of Uncontrolled Seepage

Excessive seepage can present a safety hazard to the dam and the health and welfare of people and property downstream of the dam. Most failures caused by groundwater and seepage can be classified into one of two categories based on the type of soil movement that is occurring. The failures will typically develop over a relatively long period of time so there will be ample warning if routine inspections are performed. These two categories of failures include:

1) those that take place when soil particles migrate to an escape exit and cause piping or erosion failures; and 2) those that are caused by uncontrolled seepage patterns that lead to saturation, internal flooding, excessive uplift, or excessive seepage forces.

High velocity flows through the dam embankment can cause progressive erosion and piping of the embankment or foundation soils. If this condition continues unchecked, complete dam failure can result. Saturated soil areas on the embankment slopes, the abutment, or the area at the toe of the dam can slide or slough, resulting in embankment failure. Piping and badly saturated areas can result in settlement of the soils in the embankment; excessive settlement of the dam crest can lower the height of the dam and create a potential for overtopping during storm events.

Any questions, comments, concerns, or fact sheet requests should be directed to the Division of Water at the following address:

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Additional Resources

State of Ohio, Department of Natural Resources, Division of Water, *Suggested Procedures for Safety Inspections of Dams*.

State of Ohio, Department of Natural Resources, Division of Water, *Operation, Maintenance and Inspection Manual for Dams, Dikes and Levees*.

State of Colorado, Office of the State Engineer, Division of Water Resources, *Dam Safety Manual*.

Cedergren, Harry, 1989, *Seepage, Drainage and Flow Nets*, John Wiley & Sons, New York, NY.

Department of the Army, U.S. Army Corps of Engineers, *Seepage Analysis and Control for Dams, EM 1110-2-1901*, 1993, Washington, D.C. 20314-1000

Department of the Army, U.S. Army Corps of Engineers, *Instrumentation of Embankment Dams and Levees, EM 1110-2-1908*, 1995, Washington, D.C. 20314-1000